Defence and Civil Institute of Environmental Medicine

JULY 1983 DCIEM No. 83-C-33

ACOUSTICS OF
THE PPCLI BAND REHEARSAL FACILITY
AT CANADIAN FORCES BASE CALGARY

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ABSTRACT

The rehearsal facility used by the band of Princess Patricia's Canadian Light Infantry was studied to determine if the acoustic characteristics of the room could be improved. Measurements were made of the reverberation time and of the sound exposure experienced by bandsmen during rehearsal.

It was concluded that a shorter reverberation time was desirable. Replacement of the existing suspended ceiling boards with high-performance acoustic panels was judged to be a cost-effective method of achieving the required room absorption. In those sections of the band where the loudest sound is encountered, increasing the separation between players is the obvious way to effect a reduction in exposure.

INTRODUCTION

1. Background

The band of Princess Patricia's Canadian Light Infantry (PPCLI) is a 33-piece concert aggregation featuring full brass and woodwind sections augmented by keyboards, guitars, tympani and percussion. Band rehearsals take place in a 18 by 12 metre hall having an arched ceiling and tiled floor. Sound absorption is provided by a suspended ceiling of smoothly-finished mineral board, and acoustic tile that covers about half of the wall surface. Nevertheless, the room is considered by many bandsmen to be too reverberant, and some report feelings of fatigue after rehearsals, from the loudness of the music.

In November 1980, the Base Surgeon's Office (CFB Calgary) carried out a detailed sound survey of the band room. It was suggested that absorbent material be installed as a means of reducing reverberation. At the same time it was noted that such acoustic treatment was unlikely to alter the intensity of the sound experienced by the musicians. Convinced that reduced room reverberance would be at least musically beneficial, the band considered a proposal for the installation of heavy velour drapes. Since a considerable expenditure was involved, FMC/HQ asked DCIEM to comment (1). As a prerequisite, DCIEM carried out an assessment of the band's rehearsal facilities during July 1982. The results and recommendations of the study are presented in this communication.

2. Theory of Room Acoustics

A sound source radiating acoustic waves in a room generates two co-existing fields of sound energy. The first, the direct field, has a sound pressure distribution that varies inversely as the square of the distance from the source. The second, the reverberant field, results when the direct field is redirected by the room boundaries into a complex and diffuse array of reflected waves. Unlike the direct field, the reverberant field sound pressure is essentially independent of location. The specific distance from the source where the magnitudes of the direct and reverberant fields are equal is called the room radius.

The room boundaries control reverberant energy by absorbing (converting to heat) a portion of each reflected wave. When the sound source is switched off, the reverberant field dies away gradually as each successive reflected wave is partially absorbed at the room boundaries. The time required for a 60-dB decay is called the reverberation time (RT), that varies directly with room volume and

inversely with room absorption.

Common building materials possess differing degrees of acoustic absorption, the total in any room being the sum of the absorptions of the component materials. Hard materials like concrete, plaster and glass absorb practically no sound, while soft and porous "fuzzy" materials such as glass fibre and drapery absorb much of the sound impinging upon them. The absorption of most materials varies with frequency and the method of mounting. For this reason, absorption coefficients (the fractions of incident sound absorbed by the material) are specified at six standard frequencies (125 to 4000 Hz) using one or more standard mounting configuration.

Perfect boundary absorption is said to exist at an open window, because sound energy impinging on the opening is totally removed from the environment. An opening of one square metre provides one metric Sabin of absorption.

3. Acoustical Factors in Band Room Design

In any ensemble, the musicians must be grouped together in order to hear each other. Hence, each player hears a combination of the direct sound field from neighbouring instruments, and reverberant sound from the band as a whole. The magnitude of the direct field will be greatest in the vicinity of the louder instruments. Since acoustic materials are capable of controlling only reverberant energy, the musicians subject to a higher proportion of reflected sound (ie, those situated away from the loudest instruments) will benefit most from the installation of absorptive material.

An acoustically absorptive environment offers several advantages to the musician. Most important of these is a reduction in sound exposure, to the extent that the reverberant field contributes to such exposure. Musically, the overall sound is perceived as having an "outdoor" quality, because the blending that results from reverberation is lacking. Given this condition, the band leader should find it easier to detect (and correct) any musical imperfections.

Moreover, the absence of reverberation permits the adjustment of local acoustics for special effects. For example, portable reflective surfaces can be used to reinforce the sound produced by the quieter instruments or to enhance local balance and feedback. Visually transparent diffusers suspended overhead could also be employed to advantage in some situations. Portable absorptive panels or acoustic screens would provide a degree of local sound absorption, to reduce a troublesome reflection from a hard surface, or to separate competing sources of sound. Active monitoring using microphones and loudspeakers would be easier to adjust because the sound would not be masked by room reverberance.

PROCEDURE

The on-site investigation of the PPCLI rehearsal facility consisted of: a) an assessment of the materials and fabrication techniques used in the construction of the band room, and b) the measurement of reverberation time with Ivie Electronics models IE-17A and IE-30A audio analyzers in combination with an impulsive noise source (starter's pistol). Calculations based on resulting data enabled the study of several noise control options having the potential to improve the rehearsal environment.

It was considered necessary to establish whether continuing exposure to the the sound produced during PPCLI band rehearsal could be considered potentially hazardous to hearing. Accordingly, three noise dosimeters (two Bruel and Kjaer model 4431 and one model 4425) were fitted to the shoulders of selected musicians. All three dosimeters conform to the OSHA (Occupational Safety and Health Act) exchange rate, that is, a 5-dB increment/decrement corresponds to a halving/doubling of the permitted exposure time. A Bruel and Kjaer model 4230 sound source was used for calibration. Monitoring was carried out during two regular three-hour morning rehearsal sessions of the full band.

RESULTS AND DISCUSSION

1. Sound Reduction in the Reverberant Field

The measured values of reverberation time in the band rehearsal room and corresponding calculated values of total room absorption as a function of frequency are shown in Table 1.

TABLE 1

FREQUENCY (Hz)	REVERBERATION TIME (sec)	TOTAL ROOM ABSORPTION (metric Sabins)
63	0.49	302.3
125	0.25	592.5
250	0.65	227.9
500	0.95	155.9
1000	1.04	142.4
2000	0.74	200.2
4000	0.67	221.1

The measurements indicate that the reverberation time of the rehearsal room peaks at about one second around 1000 Hz showing that the effective absorption is minimal in the mid range. The absorption provided by the tiled wall surface (estimated using Appendices A and B), subtracted from the total room absorption (Table 1) gives a good approximation of the absorption attributable to the present ceiling system (see Table 2). Additional sources of absorption (eg., people, air and furnishings) have been neglected. For comparison, the absorption of an equivalent ceiling area of high-absorbency "Sonoglas Nubby III" suspended ceiling panel (Fiberglas Canada Inc., Calgary) is listed in column 4.

TABLE 2

FREQUENCY (Hz)	ESTIMATED WALL TILE ABSORPTION (metric Sabins)	EXISTING CEILING ABSORPTION (metric Sabins)	ESTIMATED CEILING ABSORPTION WITH SONOGLAS NUBBY PANEL (metric Sabins)
125	6.4	586.1	106.9
250	9.2	218.7	200.7
500	66.9	89.0	174.5
1000	91.7	50.7	226.8
2000	91.7	108.5	233.4
4000	82.5	138.6	213.7

Comparison of columns 3 and 4 shows that at low frequencies, greater room absorption is observed than would normally be expected from even the best suspended ceilings. Most materials are less efficient at low frequencies (giving longer reverberation), hence this result suggests that a different mechanism is responsible for low-frequency absorption. It is probable that the panels comprising the main ceiling are set into resonant vibration at low frequencies, thereby converting acoustic energy into heat. At 500 Hz and above, however, the actual absorption is considerably less than potentially available from a high-performance ceiling. It was noted that the surface of the existing ceiling board was smooth and non-porous, hence it is not suprising that impinging sound is reflected rather than absorbed. It would be relatively easy to replace the existing suspended ceiling boards with high-performance Nubby acoustic panels. Since the only panel size difference is the thickness, such a modification could be implemented without changes to the existing T-bar suspension grid. Moreover, the substitution of an improved ceiling would have the desirable musical attribute of flattening the RT-versus-frequency characteristic of the room.

Under certain conditions, arched ceilings may focus ceiling-reflected sound. In the PPCLI rehearsal space, however, the effective radius of curvature is greater than the floor-to-ceiling height, and only diffuse focusing of sound back into the band should be possible. A highly absorptive ceiling would of course minimize all ceiling reflections, including those with the potential to create "hot spots".

2. The Macphon Proposal

Macphon Industries has proposed the installation of 25-ounce velour drapes in the band room as a means of controlling reverberation. Drapes can be considered as an adjustable source of absorption, depending on the area of wall they are set to cover. Although of significance in an auditorium environment where the reverberation can be optimally matched to the style of music being performed, this is not deemed a significant requirement for rehearsal.

Full extension of the drapes as proposed necessitates the coverage of considerable surface area already treated with good quality acoustic tile. Since there is little to be gained by adding absorption to a surface that already reflects negligible sound, the addition of drapery would be redundant, except at low frequencies, where the tile absorption is minimal. Estimates of the drape-over-tile absorption coefficients are given in Appendix B.

The total potential room absorption available with the drapes fully extended is compared in Table 3 with that which could be provided by more efficient ceiling panels.

TABLE 3

FREQUENCY (Hz)	MEASURED TOTAL ROOM ABSORPTION AS IS (metric Sabins)	ESTIMATED TOTAL ROOM ABSORPTION DRAPES IN (metric Sabins)	ESTIMATED TOTAL ROOM ABSORPTION NEW CEILING (metric Sabins)
125	592.5	625.8	592.5
250	227.9	287.8	227.9
500	155.9	212.3	241.4
1000	142.4	202.3	318.5
2000	200.2	261.0	325.1
4000	221.1	282.6	296.2

The measured values of absorption at 125 and 250 Hz (believed to be largely independent of either proposed reverberation control system) have been used in columns 3 and 4. A high-performance acoustic ceiling shows the greatest potential for improvement of the rehearsal environment over the frequency range considered most important for musical production. Moreover, the estimated materials cost is less than $3,000, or about $17,000 less costly than the drapes.

3. Noise Exposure During Rehearsal

The values of "noise dose" accumulated by the dosimeters worn on the musicians' shoulders, and corresponding three-hour equivalent OSHA levels (L_{OSHA}), are given in Table 4.

TABLE 4

MUSICIAN	PER CENT OF DAILY PERMISSIBLE EXPOSURE EXPERIENCED DURING 3-HOUR REHEARSAL	L_{OSHA}, dBA
Tuba (left)	56%	91.8
2nd Trumpet	56%	91.8
Euphonium	62%	92.5
Trombone (right)	101%	94.5
Trombone (left)	85%	93.5
Keyboards	63%	92.5

When a count of 100 per cent is accumulated, the maximum permitted exposure for the day is considered to have been reached (2). Note that additional exposure (to small group practice or non-occupational noise) could add to the percentages. The exposure doses shown may be considered typical, but additional monitoring would certainly indicate some variation from practice to practice. The data do suggest, however, that certain bandsmen (notably the trombone players) may be at marginal risk because of their proximity to the trumpet line. Otherwise, practicing does not appear to be potentially hazardous to hearing. The survey of Forshaw and Cruchley (3) carried out after this study suggests indeed that noise over-exposure is not a significant occupational hazard for musicians in the Canadian Forces at large, but does not preclude the possibility that certain noise-susceptible individuals may be over-exposed during the course of their work.

The room radius (the distance at which the magnitude of the direct and reverberant fields are equal) was calculated to be about 2.5 metres for directional instruments such as trumpets and 1.8 metres for non-directional instruments, given the existing conditions of room reverberation. The addition of acoustic materials would, of course, increase these distances in proportion to the the absorption added.

However, it is evident that the sound exposure experienced by musicians within the room radius of nearby instruments cannot be significantly reduced by the addition of materials to the room boundaries.

Since the sound exposure accumulated by any musician over a period of time depends on both sound pressure level and duration, a reduction in either quantity will effect a corresponding reduction in exposure. Less daily rehearsal time would, of course, be counter-productive, but there is an aural advantage to dividing the traditional three-hour morning rehearsal into two shorter sessions separated, for example, by the lunch break. Such a period of relative silence would give the musicians' ears a chance for at least partial recovery from the first exposure.

It is acknowledged that the floor layout in current use by the the PPCLI band represents the best musical compromise between overall balance and ensemble considerations. Nevertheless, an increase in the separation between players would benefit those musicians exposed to the loudest direct sound fields.

CONCLUSIONS AND RECOMMENDATIONS

1. The addition of sound-absorptive materials to the PPCLI rehearsal space would improve the acoustics of the facility through a reduction in reverberant sound levels. Suggested systems for adding room absorption are: a) acoustic drapes installed on the wall surfaces (as proposed by Macphon Industries), and b) replacement of the existing suspended ceiling board with high-performance material. In addition to the benefit of superior absorption, implementation of the latter option would save an estimated $17,000.

2. A significant reduction in sound exposure for musicians positioned close to loud instruments cannot be effected by adding acoustic materials to the environment. However, a) increasing the distance to nearby musicians, and/or b) a change in the practice schedule to permit discrete periods of relative quiet would have the desired effect.

3. With the exception of certain brass players who may be marginally at risk, rehearsing in the PPCLI band does not appear to be potentially hazardous to hearing in the long term.

REFERENCES

1. Message, SURG 422, 311735Z MAY 82.

2. Canada Noise Control Regulations (1973), Part IV of the Canada Labour Code (Safety of Employees).

3. Forshaw, S.E., Cruchley, J.I., A review of the hearing categories of Canadian Forces Personnel. DCIEM Report in preparation.

ACKNOWLEDGEMENT

The authors are grateful for the assistance and co-operation provided by the Commanding Officer and members of the PPCLI Band during the data-gathering phase of this study.

APPENDIX A

PPCLI BAND PRACTICE ROOM STATISTICS

Length	18.3 m
Width	11.8 m
Height, at side	3.4 m
Height, at centre	5.4 m
Volume, excluding practice booths	920 cu m
Ceiling area, excluding practice booths	218.1 sq m
Wall area treated with acoustic tiles	91.7 sq m
Plenum depth between main and suspended ceilings	0.46 m

The following data are based on measurements given in the Macphon Proposal for the installation of 25-ounce velour drapes:

Drapery area excluding practice booths with wall coverage to 3.4 m above floor	151.6 sq m
Tiled wall area on room ends above drapes	25.7 sq m
Tiled wall area covered by drapes	66.0 sq m
Untreated wall area covered by drapes	85.6 sq m

APPENDIX B

MATERIAL ABSORPTION COEFFICIENTS

Assumed absorption coefficients for 19-mm perforated glass fibre acoustic tile directly mounted to hard plaster surface:

FREQUENCY (Hz)	ABSORPTION COEFFICIENT
125	0.07
250	0.10
500	0.73
1000	1.00
2000	1.00
4000	0.90

Published absorption coefficients for 25-mm "Sonoglas Nubby III" glass fibre ceiling board suspended 0.41 m below main ceiling structure:

FREQUENCY (Hz)	ABSORPTION COEFFICIENT
125	0.49
250	0.92
500	0.80
1000	1.04
2000	1.07
4000	0.98

Assumed absorption coefficients of proposed 25-ounce per square yard velour curtains draped to half area:

FREQUENCY (Hz)	ABSORPTION COEFFICIENT
125	0.25
250	0.43
500	0.62
1000	0.70
2000	0.71
4000	0.68

APPENDIX B CONTINUED

Assumed composite absorption coefficients of velour drapes over acoustic tile:

FREQUENCY (Hz)	ABSORPTION COEFFICIENT
125	0.25
250	0.45
500	0.78
1000	1.00
2000	1.00
4000	0.95

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